CHAPTER 4

Tree Island Habitat Suitability Index

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General Description

Tree islands, such as those shown in **Figure 4-1**, are a unique and important component of the Everglades landscape (Loveless 1959, Dineen 1974, Zaffke 1983, Sklar and van der Valk 2002). Tree islands support high plant species diversity, provide nesting habitat for a variety of wetland reptiles and birds, and serve as wet-season refuges for upland animals such as white-tailed deer (Loveless and Ligas 1959). Although the total area of all tree islands combined may be only 5 to 10 percent of the Everglades (Schneider 1966), this small portion of the landscape supports more species of birds and animals than any other habitat (Gawlik and Rocque 1998).

Figure 4-1. Tree islands in the ridge and slough landscape of the Everglades.

1. United States Fish and Wildlife Service, South Florida Field Office

2. South Florida Water Management District

Tree islands are complex and diverse forest ecosystems that comprise a variety of plant communities associated with different hydroperiods, climatic regions, soils, and salinities (Armentano et al. 2002). Island topographical highs are usually 1.0 to 3.0 feet higher than the surrounding wetlands (Loveless 1959), although some islands rise as much as 5.0 feet or more above the marsh (Heisler et al. 2002). Surface elevation slopes are extremely gradual and are associated with gradients in vegetation, especially along the long axis of the many teardrop shaped islands. Relatively small changes in water depths and durations can thus produce distinct shifts in island hydroperiods, which in turn alter the vegetation communities that the island can support (McPherson 1973). Vegetation shifts may also occur without changes in water depth if island elevation is lowered as a result of soil oxidation (Loveless 1959). Although the size of tree islands can range from less than one acre to as large as a several hundred acres, the proportion of an island that is relatively elevated (i.e., more than 1.5 feet above the surrounding marsh) is typically less than 0.25 acres (Heisler et al. 2002). Thus changes in water depth may profoundly affect the spatial extent of the shorter hydroperiod, drier portions of tree islands that provide scarce habitat for hammock plants and terrestrial animals.

Tree islands in the central Everglades have been dramatically altered by hydrologic changes during the past century. Drought, fire, and prolonged flooding of islands have been reported to be the principal sources of damage to island vegetation and soils (Loveless 1959, Dineen 1972, McPherson 1973, Schortemeyer 1980, Guerra 1996). In Water Conservation Area (WCA) 2A, more than 85 percent of islands were reported to have disappeared during high water conditions that occurred between 1965 and 1970 (Dineen 1974, Wu et al. 2002). In WCA 3A and WCA 3B, the spatial extent of tree islands decreased by more than 60 percent between 1940 and 1995 (Sklar and van der Valk 2002).

Restoration of degraded tree islands and protection of intact islands are among the goals for restoration of the Everglades ridge and slough ecosystem. Current restoration plans predict dramatic changes in depth patterns over portions of the ridge and slough landscape that have large numbers of tree islands. Therefore, performance measures based on currently available data and analysis are needed to evaluate the effects of proposed hydrologic changes on island ecology, topography, and spatial extent.

Hydrologic Variables

Hydrologic variables considered influential in maintaining tree island habitat include threshold high and low depths tied to durations above or below these thresholds. Tree island habitat suitability indices focus on effects of hydrology on hardwood hammocks and elevated portions of bayhead tree islands in the ridge and slough region. The rationale for this is that if the hydrologic conditions needed to support hammock communities on the highest tree islands are restored, in conjunction with restoration of marsh depth patterns that will maintain sawgrass ridge and slough communities, then the overall hydropattern should implicitly include conditions that would support the full range of tree island vegetation types, from the most to the least hydric, at appropriate elevations and locations within the landscape.

Simulation results from the Everglades Landscape Vegetation Model (ELVM) have suggested that duration of island inundation is a major factor contributing to tree island development and stability in the Everglades. Landscape models by Wu et al. (2002) have shown that patterns of loss of spatial extent of tree islands in WCA 2A and WCA 3A can be approximated using models that focus on the depth and duration of island flooding across the landscape.

Fire is a natural process in the Everglades. However, drainage and impoundment of the Everglades during the past century has increased the duration of dry periods and the frequency, intensity, and spatial extent of fire. This has led to extensive loss of peat soils both in the marshes and on tree islands, as well as to destruction of tree island vegetation (Loveless 1959, Schortemeyer 1980). Schortemeyer (1980) estimated that by the 1980s, tree islands in northern WCA 3A had lost as much as 95 percent of their soil volume at low-to-intermediate elevations.

In addition to the impact of intense fires on soils and tree island vegetation, soil loss has altered the topography of the Everglades. Peat-consuming fires and oxidation have caused widespread surface subsidence throughout the ridge and slough landscape (Stober et al. 1998). It is not presently known whether tree islands and marshes have lost soil at similar or different rates, but recent work suggests that overdrained areas of the Everglades have suffered a reduction in topographic heterogeneity, including a reduction in the depth of sloughs that would serve as natural fire breaks (SCT 2003). Oxidized soils also become enriched in nutrients, which can promote the spread of cattail monocultures and other vegetation changes.

Two specific hydrologic variables were selected to serve as general indicators of prolonged low and high water conditions. These variables were chosen because they were found to be good statistical predictors of tree island species richness (Heisler et al. 2002). The indicator for prolonged low water conditions was the percent of time that ground water receded more than 1.0 feet below model grid cell ground surface. The indicator for prolonged high water conditions was the percent of time that depths exceeded 2.0 feet above model grid cell ground surface. This benchmark was chosen on the following rationale. Because tree islands vary in elevation, no single depth/duration measure can indicate the same intensity of flooding for all islands. However, a common benchmark is required if model output is to be evaluated across the ridge and slough landscape.

Habitat Suitability Functions for Tree Islands

The habitat suitability indices presented here are founded on different theoretical rationales and use different types of supporting information. The first index, a species richness suitability index, employs a measure derived from statistical analysis of vegetation and hydrologic data for tree islands in WCA 3A. The Natural System Model version 4.5 (NSM) is then used to identify hydrologic targets for this measure (SFWMD 1998). The second index, a tree island suitability index is based on simple dynamic models of tree island stress and recovery, using parameters derived from the published literature, field observations, and landscape vegetation models (Wu et al. 1996, 1997, 2002). Tree island suitability functions were developed based on hydrologic parameters for the 2-mile by 2-mile grid cells of the South Florida Water Management Model (SFWMM) and the NSM and applied to grid cells for the ridge and slough landscape (**Figure 4-2**), which is the area within which tree islands predominantly occur.

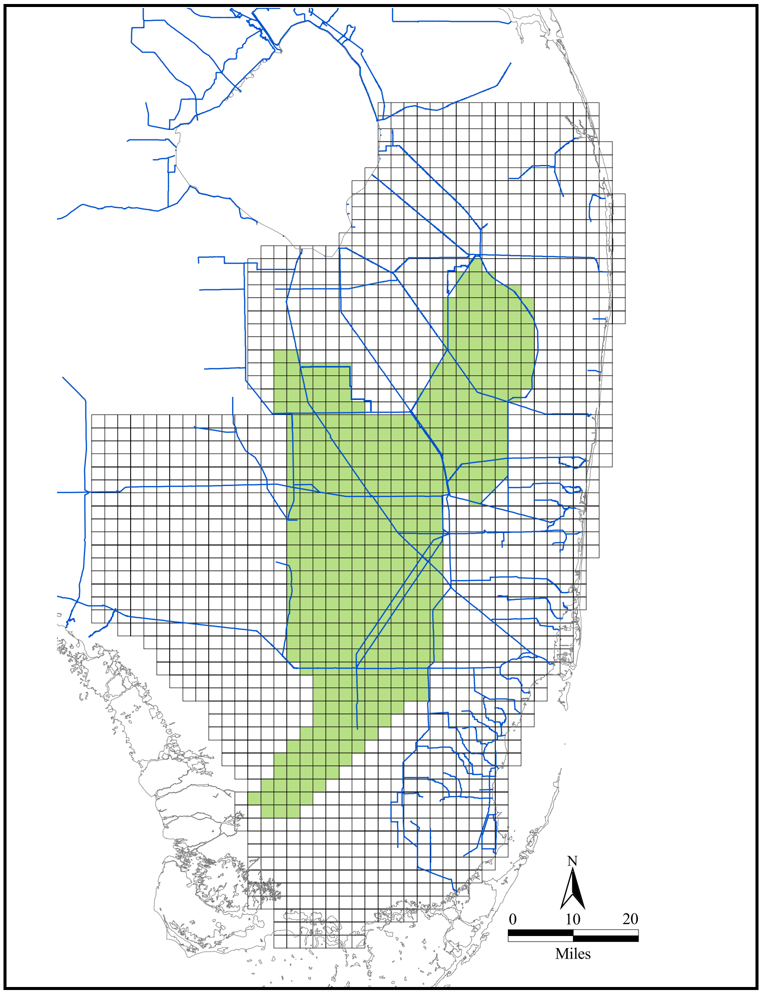


Figure 4-2. SFWMM grid cells applicable for the tree island habitat suitability index.

Species Richness Suitability Index

The species richness suitability index (SRSI) is based on a statistical relationship between estimated hydrologic conditions during 1979 to 1995 and field data from 1997 to 1999 on tree island vegetation on hammocks and elevated bayheads in WCA 3A. The approach to defining the index entailed two steps. First, regression analysis was used to develop a predictive equation relating hydrologic model output to field-collected data on tree island vegetation. The regression equation defined an aggregate hydrologic variable that combines and weighs its component measures in a manner that best explains observed variance in tree island vegetation condition. The second step involved rescaling this variable into a suitability index that measures how well a given water management scenario matches predrainage hydrology for this measure, using estimates provided by the NSM (SFWMD 1998).

A number of statistically significant associations between hydrology and vegetation were identified, including hydrologic predictors of species richness, vegetation cover, and island spatial extent (Heisler et al. 2002); however, one vegetation variable stood out in the analysis: the number of tree and shrub species observed in vegetation transects exhibited both the largest proportion of variance explained by hydrologic variables and a statistically significant negative association with both the frequency of extreme low ground water conditions and the frequency of island flooding. This result confirmed and extended earlier inferences based on eyewitness observations (e.g., Loveless 1959, Guerra 1996) and smaller field studies (e.g., McPherson 1973, Dineen 1974) that prolonged drought and prolonged high water conditions are both causes of damage to tree island vegetation in the Everglades water conservation areas.

Heisler et al. (2002) reported that the statistically best predictor of the relationship between high water conditions and species richness was the percent of weeks during 1979-1995 in which islands in WCA 3A were estimated to have been flooded within 1.0 feet of their maximum elevation. Their analysis was based on species richness data from a sample comprised of the highest island in each of 22 SFWMM grid cells, and these islands averaged approximately 3.0 feet in maximum height. Thus, 2.0 feet corresponds to a depth above which the highest islands in a representative sample of WCA 3A grid cells would be flooded to a degree that predicts a reduction in species richness. Note that the measure does not imply that *any* depths over 2.0 feet are damaging, only that the cumulative effects of longer durations above 2.0 feet appear to be so. Using the above hydrologic indicators, a score for predicted species richness (PSR) is defined as follows:

$$PSR = 13.4 - 0.75(LO\%) - 0.10(HI\%)$$

where LO% is the percent of weeks in the simulation period with mean weekly depth less than -1.0 feet and HI% is the percent of weeks with mean weekly depth greater than 2.0 feet.

PSR thus provides a measure of the decrease in the number of tree and shrub species, relative to a maximum of 13.4, that would be predicted to occur on a hypothetical 3.0-foot high tree island in the model cell in question. Note that PSR should be constrained to a minimum value of zero; however, negative values for PSR have not yet been obtained using SFWMM or NSM (SFWMD 1998, 1999) output for ridge and slough model cells.

Figure 4-3 illustrates the degree to which PSR predicts observed species richness on tree islands in WCA 3A and 3B. PSR appears to predict observed values fairly well for islands in the range of 2.5 to 3.5-foot maximum elevation. PSR is less accurate in predicting species richness on higher or lower islands. This suggests that the flooding depth criterion of 2.0 feet is appropriate as an indicator of flood stress to “typical” elevated islands, but may not be as good a tool for evaluating potential hydrologic impacts to higher or lower tree islands.

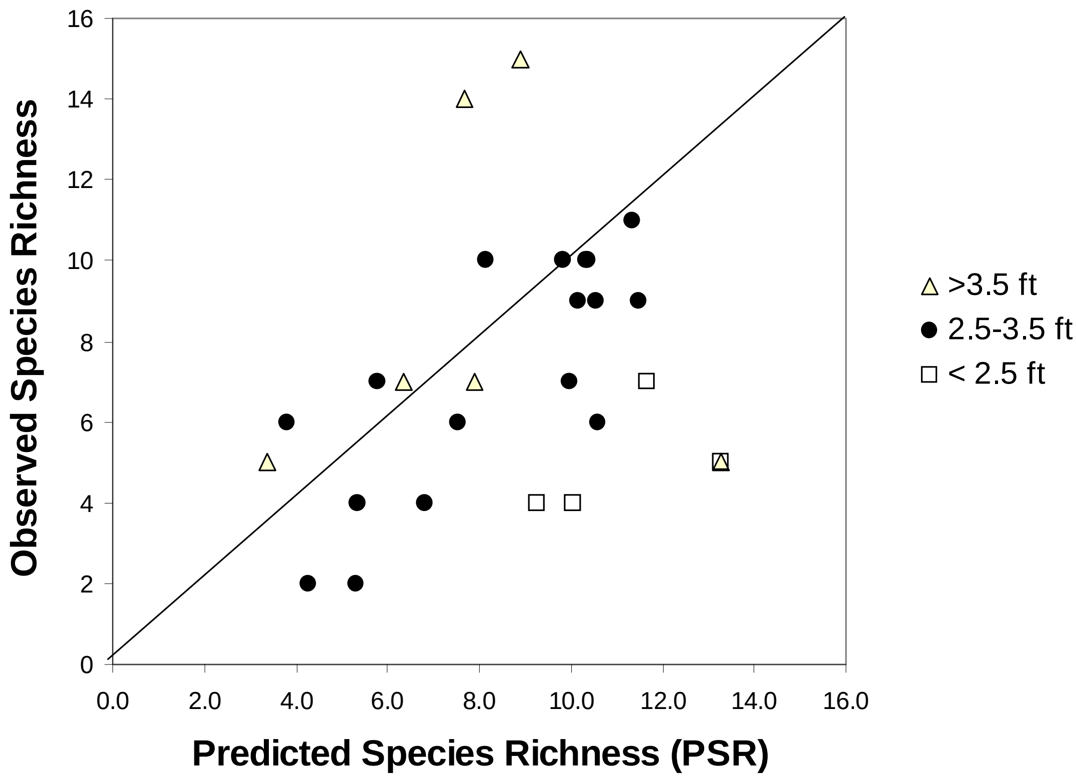


Figure 4-3. Relationship between predicted and observed species richness for tree islands in WCA 3A and 3B. Symbols show islands in three different categories based on maximum island elevation above the slough. The solid diagonal line indicates cases of a perfect fit between PSR and observed values.

PSR provides a joint hydrologic score that reflects areas of both flood and drought impacts using a single measure. This combined score avoids the interpretive complications that arise from using separate measures for drought and flood impacts that can allow a negative score on one measure to be offset by a positive score on the other. Local hydrology must be suitable at both ends of the hydrologic range in order for a grid cell to receive a high value of PSR.

A standardized value of PSR, denoted PSR*(c,x), is defined as the deviation of PSR in grid cell c of model x from the value predicted by NSM for the same grid cell, divided by the spatial standard deviation, σ_{NSM}, of PSR(c,NSM) calculated over all cells in a defined portion of the ridge and slough landscape:

$$PSR^*(c,x) = [PSR(c,x) - PSR(c,NSM)] / \sigma_{NSM}$$

Rescaling of PSR to standard deviation units creates a relative measure that avoids potential misinterpretation of PSR as a literal prediction of future species richness. It also creates a scale of measurement that allows differences in PSR to be related to the landscape pattern of variation in predicted species richness under simulated predrainage conditions. Standardization relative to NSM underscores that species richness is serving as an ecological response variable that identifies relevant variation in hydrology, and is not being set as the restoration goal for tree islands per se.

PSR*(c,x) can be defined for any single grid cell or group of grid cells c and any particular model x. For example, PSR*(c,x) could be defined for every grid cell in a water conservation area for a particular run of the SFWMM, and normalized using the NSM standard deviation for the same group of cells. Alternatively, NSM values for all cells in the historical ridge and slough landscape could be used to normalize PSR.

The last step in developing the habitat suitability index is to define the Species Richness Suitability Index (SRSI) that maps PSR* to the interval (0,1) as follows:

$$\text{SRSI}(c,x) = 1.0 \qquad \text{if PSR}^*(c,x) \geq 0.0$$

$$\text{SRSI}(c,x) = 1.0 + \text{PSR}^*(c,x)/2 \qquad \text{if } -2.0 < \text{PSR}^*(c,x) < 0.0$$

$$\text{SRSI}(c,x) = 0.0 \qquad \text{if PSR}^*(c,x) \leq -2.0$$

This index is illustrated by the solid line in **Figure 4-4**. Here, a grid cell or group of cells receives the maximum score of SRSI = 1.0 if the predicted species richness meets or exceeds that predicted under NSM hydrology. If predicted species richness falls below the value predicted by NSM, SRSI decreases linearly to a minimum of zero when PSR(c,x) is two or more standard deviation units lower than the NSM value for the grid cell. Cells that score zero have predicted species richness values close to or below the low end of the range of values predicted by NSM for the reference set of ridge and slough grid cells.

An alternative SRSI is illustrated by the dashed line in **Figure 4-4**. In this case, only PSR values that deviate from NSM by more than one standard deviation unit receive less-than-perfect scores, and cells that predict too many species are penalized along with cells that predict too few. Results for this alternative SRSI are not included in this report.

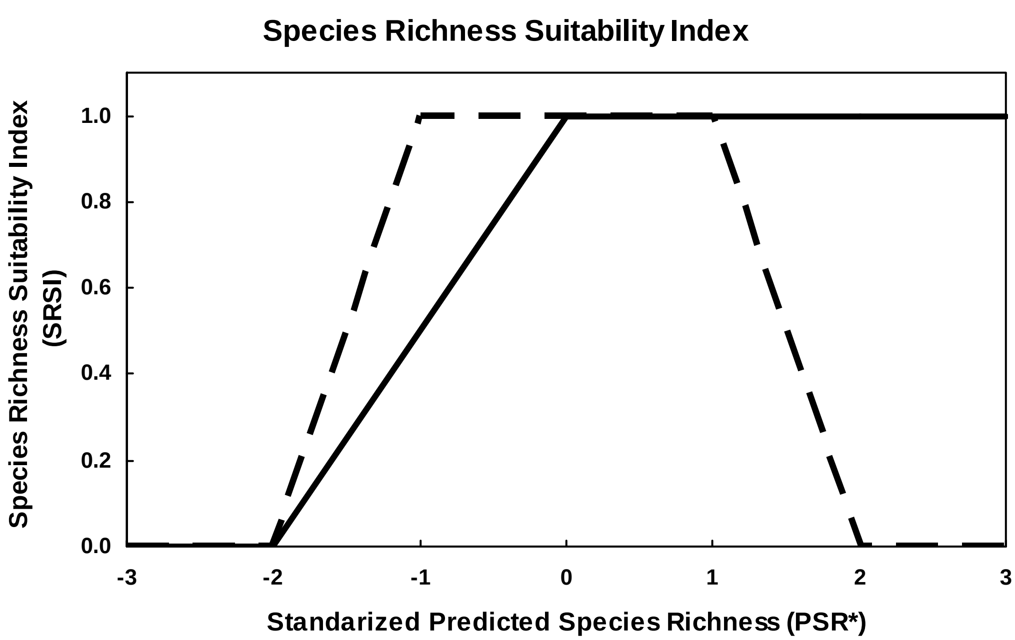


Figure 4-4. Species richness suitability indices (SRSI) for tree islands.

The SRSI is appropriate for evaluating model-to-model differences in the potential for adverse impacts to elevated tree islands over a multi-decade time scale. SRSI does not attempt to predict optimal depth conditions for tree island restoration, nor is it applicable as a performance measure for lower-elevation islands.

Tree Island Suitability Index

An alternative approach to developing habitat suitability indices is to construct a time series model that mimics the effects of flood stress and fire risk to tree islands over time. This approach uses information developed from landscape vegetation models that aim to provide realistic, dynamic models of vegetation change (Wu et al. 1996, 1997, 2002). Daily indices are developed to represent how flooding stress during high water periods and risk of fire during dry periods wax and wane as conditions vary. By providing a time series of values, this dynamic modeling approach may prove useful in identifying which specific hydrologic events or water management practices appear to be most likely to impact tree islands. A difficulty with the approach, however, is that the model parameters needed to characterize the rates at which stress and recovery occur are not presently known. These parameters must be inferred from field observations and reports in the literature, and they must be fitted during calibration of the model.

Flood Index

Based on Loveless' 1959 report that tree islands range from 1.0 to 3.0 feet in elevation relative to the surrounding marsh, along with more recent data on tree island elevations, a depth criterion of 2.0 feet was chosen for evaluating flooding stress to tree islands. Systematic studies of the relationship between the duration of tree island flooding and the time course of impacts to tree island species have not been conducted; hence, it is necessary to estimate the rate of deterioration of tree island condition from limited reports and field observations on the duration of flooding associated with noticeable stress at one extreme and widespread tree mortality at the other. Sixty days of continuous flooding above 2.0 feet was selected as an estimate of the point at which typical tree island species would begin to experience negative impacts, and 300 days of continuous flooding above 2.0 feet was selected as an estimate of the point at which extensive mortality would be expected. Given these assumptions, a daily flood index, DFI, is defined as the score for day t of the time series as follows:

$$DFI(t) = 1.0 / \{1.0 + 0.0023 \exp[0.039 \cdot CFD(t)]\}$$

where $t = 1, \ldots, 365N$, for simulation of N years and CFD(t) is the cumulative flood duration in number of days of flood stress as of day t.

The shape of this DFI function is illustrated in **Figure 4-5**. The parameters of the above equation were chosen so as to set DFI(t) ~1.0 when CFD(t) = 60 days, and to allow continuous decrease in DFI(t) until DFI(t) ~ 0.0 when CFD(t) $\geq$ 300 days.

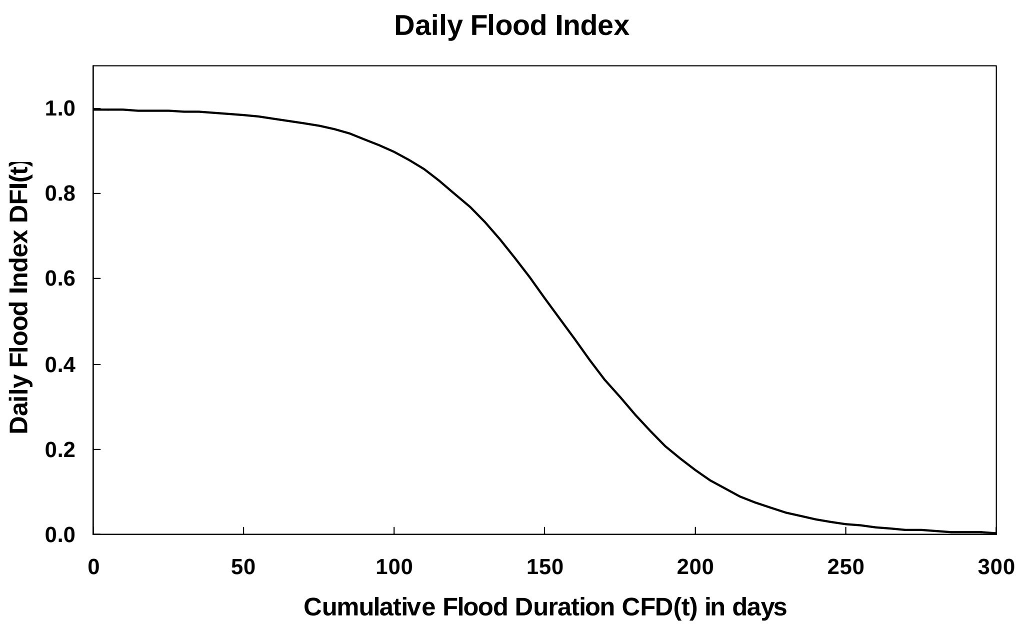


Figure 4-5. Daily flood index (DFI(t)) as a function of cumulative flood duration in days (CFD(t)).

The CFD(t) function defines the method for counting cumulative flood days as a function of water depths at time t, WD(t), as follows:

CFD(t) = CFD(t-1) + 1.0	if WD(t) > 2.0 feet
CFD(t) = CFD(t-1) - 0.5	if WD(t) is $\leq$ 2.0 feet and CFD (t-1) > 0.5
CFD(t) = 0	if WD(t) is $\leq$ 2.0 feet and CFD (t-1) $\leq$ 0.5

CFD(t) increases by the equivalent of one "flood day" for each additional day that water depth remains above 2.0 feet, and CFD(t) decreases by the equivalent of 0.5 "flood days" for each day depths have receded below 2.0 feet.

After examining several options (e.g., long-term mean and long-term minimum), the mean value over all years of the annual minimum of DFI(t) was selected as a summary measure of flood stress. This measure, the mean annual minimum flood index (MAMFI), provides an indication of the average maximum flood stress experienced by islands on an annual basis. For a time series of N years, MAMFI is defined as follows:

$$\text{MAMFI} = \sum_{i=1}^{N} \text{minDFI(i)/N}$$

where minDFI(i) is the minimum value taken by DFI(t) during year i.

Drought Index

The drought index proposed here is a dual-purpose tool. It can serve both as an index for assessing potential tree island impacts from drought, and as a stand-alone performance measure for evaluating the risk of peat-consuming wildfires in the overall ridge and slough landscape. Based upon review of historical records and the scientific literature, a depth of 1.0 feet below ground surface was selected as the best current estimate of the depth of ground water recession in peat marshes below which the risk of peat-consuming wildfires becomes excessive (SFWMD 2000).

The daily drought index, DDI(t), is defined as a time-dependent function of two variables: water depth, WD(t), and cumulative drought duration, CDD(t). CDD(t) is the number of sequential days up to and including day t during which depths were below ground surface, calculated as follows:

$$\mathrm{CDD}(t) = 0 \qquad \text{if } \mathrm{WD}(t) > 0.0 \text{ feet}$$

$$\mathrm{CDD}(t) = \mathrm{CDD}(t-1) + 1 \qquad \text{if } \mathrm{WD}(t) < 0.0 \text{ feet}$$

The daily drought index is then defined as follows:

$$\mathrm{DDI}(t) = 1.0 \qquad \text{if } \mathrm{WD}(t) > 0.0 \text{ feet}$$

$$\mathrm{DDI}(t) = \frac{1.0 - 0.0035\mathrm{CDD}(t)}{1.0 + 0.010\exp\{-4.6\mathrm{WD}(t)\}} \qquad \text{if } \mathrm{WD}(t) < 0.0 \text{ feet}$$

Note that a single day with WD(t) > 0.0 feet is assumed to “break” the drought by resetting CDD(t) to zero and DDI(t) to unity. **Figure 4-6** illustrates the dependence of DDI(t) on the two variables. The numerator of DDI(t) decreases from a maximum of 1.0 when surface water is present to a minimum of zero when CDD(t) reaches 285 days. The coefficient 0.0035 is an approximate measure of the daily increase in the risk that a cell will be included in a wildfire (Wu et al. 1996). The denominator of the above equation serves to decrease the value DDI(t) as ground water recedes further below the surface. This feature of the index is intended to mimic the increased risk of intense and damaging muck fires when the soil has dried to greater depths.

The arithmetic average of the annual minimum of DDI(t) is proposed as a measure of long-term risk of fire, with increasing values of the index reflecting a decrease in the average annual risk. This mean annual minimum drought index (MAMDI), is defined for a series of N years as follows:

$$\mathrm{MAMDI} = \sum_{i=1}^{N} \mathrm{minDDI}(i)/\mathrm{N}$$

where minDDI(i) is the minimum value taken by DDI(t) during year i.

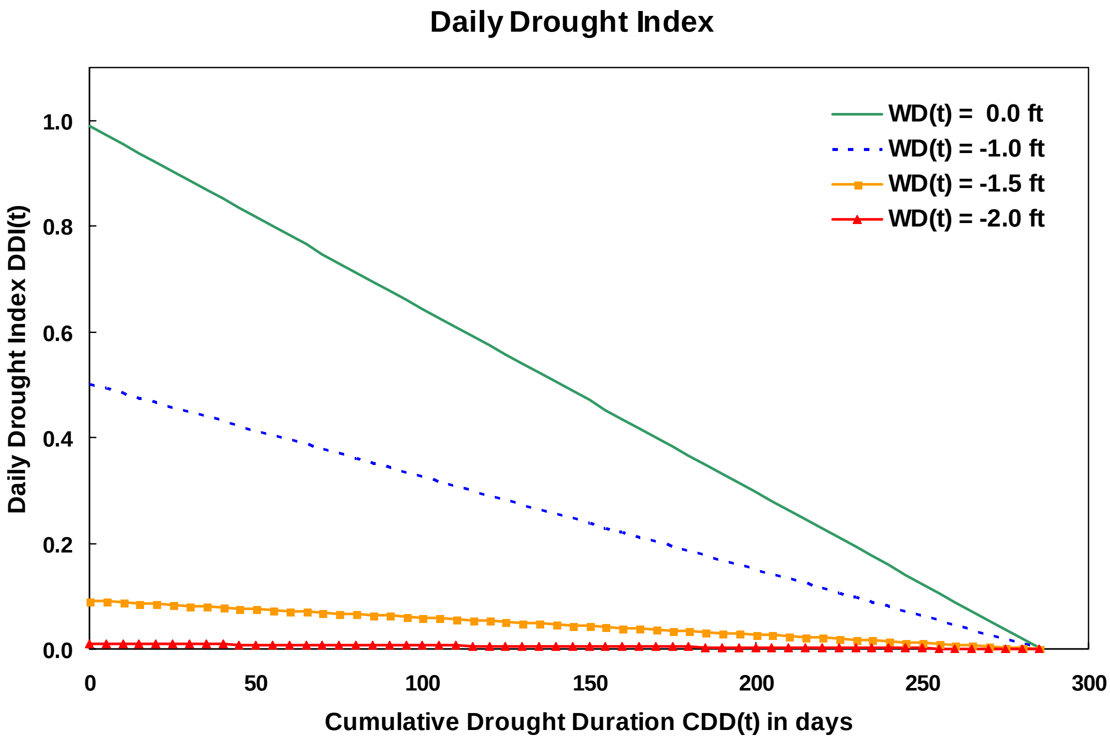


Figure 4-6. Daily drought index DDI(t) as function of cumulative drought duration in days CDD(t) and water depth below the surface WD(t).

Tree Island Suitability Index

In order to evaluate the combined effects of flood and drought on tree islands, the overall tree island suitability index (TISI) is defined as follows:

$$\mathrm{TISI} = \sum_{i=1}^{N} \mathrm{minDDI(i)} \cdot \mathrm{minDFI(i)/N}$$

This equation assigns, for each year, a value that is at most as large as the smaller of the two indices during that year. TISI is then the long-term mean of these values. This formulation insures that high scores for one index during a given year cannot mitigate the impact of a low score for the other index. This prevents flood and drought year values from canceling each other out. It also compounds the effect of flooding and drought in any year by making the overall TISI value less than each of the individual flood or drought indices.

An alternative formulation of TISI is to use the annual minimum of the MAMFI and MAMDI. This assigns a value for each year that is equal to the smallest value taken by either index during the year. An alternative tree island suitability index, not discussed further in this report, could be defined as follows:

$$\mathrm{TISI_{alt}} = \sum_{i=1}^{N} \mathrm{min[DDI(i), DFI(i)]/N}$$

Results

The suitability indices developed above have not been subject to rigorous evaluation and cross-validation. However, the following sections present some initial results and observations relevant to the performance of these indices as plan evaluation tools for the simulated natural, current, and restored systems.

Species Richness Suitability Index

PSR scores for the natural system (**Figure 4-7a**) are relatively high throughout the ridge and slough landscape. Since the derivation of PSR was based on empirical data that are independent of NSM results, this lends support to the notion that restoration of natural hydrology would be expected to contribute to the restoration of tree island vegetation communities. Under current system hydrology, PSR scores (**Figure 4-7b**) are relatively low in areas where there has been a shift away from natural system hydrology through excess drying in northern WCA 3 and the Rotenberger Wildlife Management Area or excess high water to the northwest of the L-67 canal and in southern Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR) and WCA 2B. For the hydrology of the restored system, PSR scores (**Figure 4-7c**) improve relative to the current system for most of northern WCA 3, for the Rotenberger Wildlife Management Area, and along the L-67 canal. These observations lend mutual support for both PSR as a performance measure and the natural system as simulated using the NSM model as a suitable planning target. However, PSR by itself is not a suitable metric for evaluating tree island condition, because maximization of species richness per se is not a restoration goal. Rather, it is expected that hydrologic restoration would support the recovery of tree islands to levels of biodiversity that are comparable to those that existed prior to drainage of the Everglades. Hence, evaluation of hydrologic models is based on SRSI, which measures the deviation of PSR from a target based on simulated natural system hydrology.

The spatial distribution of SRSI (calculated using the solid line in **Figure 4-4**) for the current and restored systems (**Figure 4-8**) suggests that the restoration plan would improve tree island condition through most of WCA 3A, WCA 3B, and Shark River Slough. Slight improvements are predicted for the Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR). In WCA 2A, SRSI predicts improvement in the northern part of the water conservation area but negative impacts in the central and southern regions.

Tree Island Suitability Index

Components of the TISI are the annual minimum flood and the annual minimum drought indices. Examination of the mean values of these two indices provides information on their individual performance.

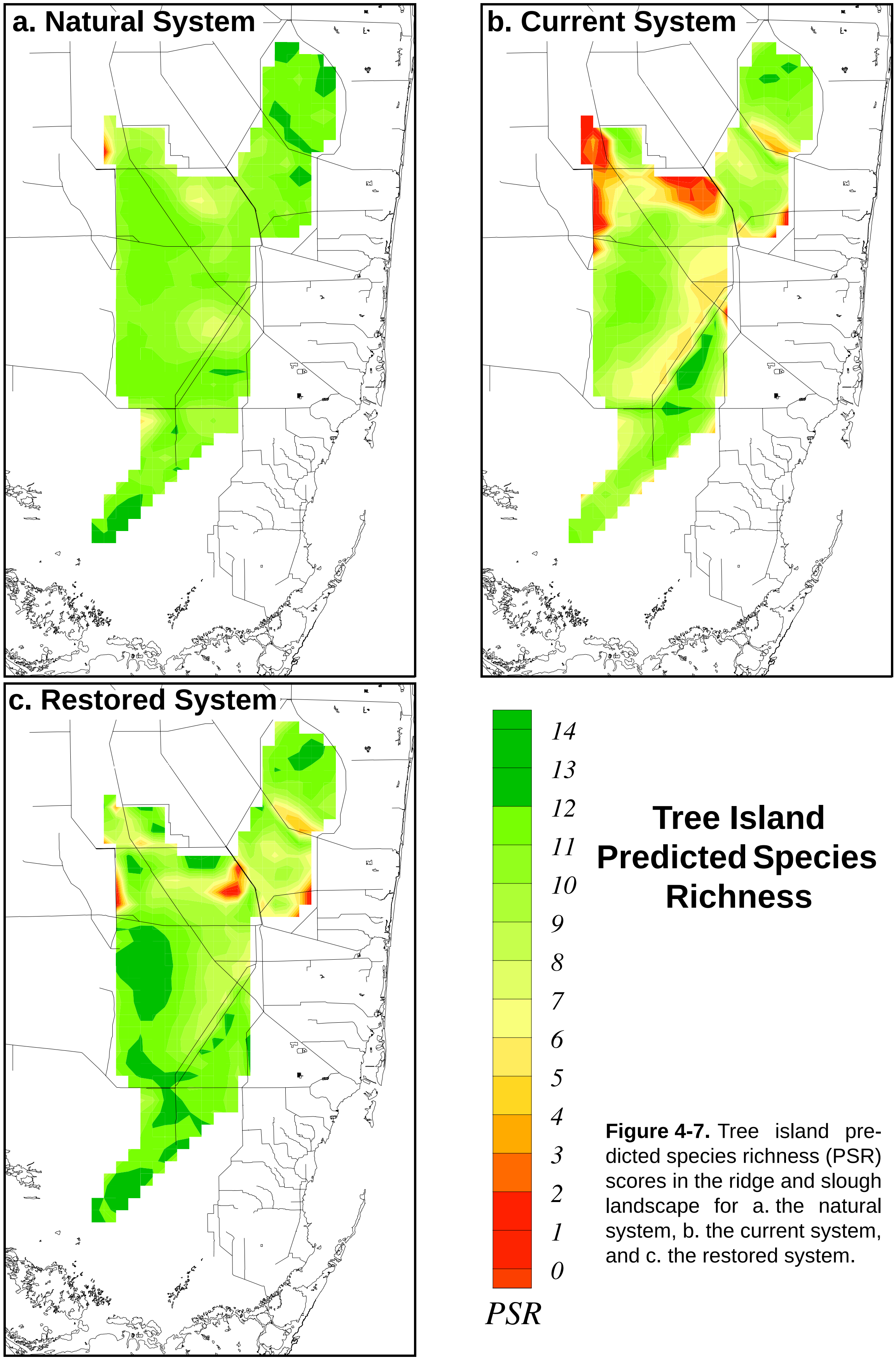


Figure 4-7. Tree island predicted species richness (PSR) scores in the ridge and slough landscape for a. the natural system, b. the current system, and c. the restored system.

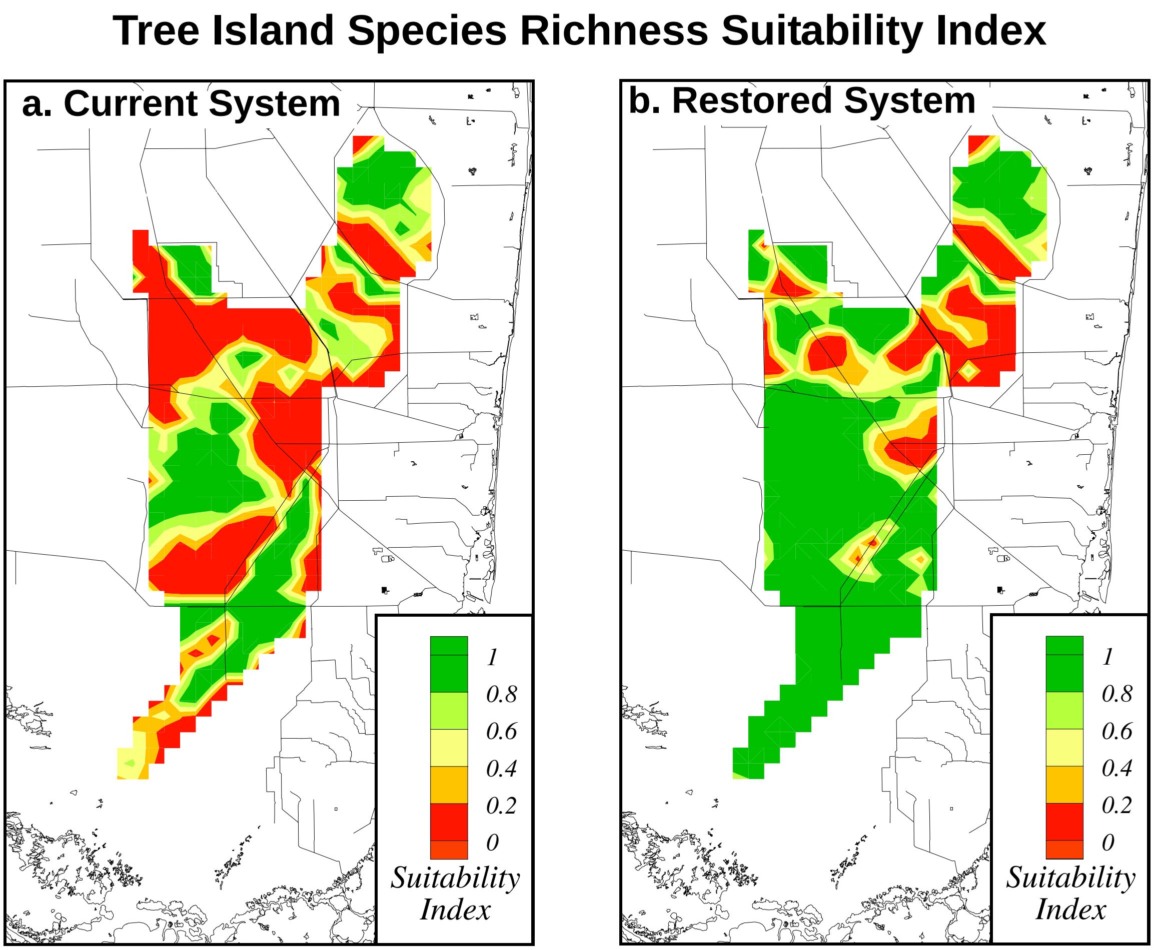


Figure 4-8. Tree island species richness suitability index (SRSI) in the ridge and slough landscape for the a. current system and b. restored system. By definition, SRSI = 1.0 for all cells for the NSM.

Flood Index

The spatial distribution of MAMFI for the natural, current, and restored systems is illustrated in **Figure 4-9**. For the current system, the MAMFI correctly identifies the regions where tree island flooding has been common during recent decades, namely southern LNWR and southern and eastern WCA 3A (**Figure 4-9b**). In the restored system, improvements are predicted in southern WCA 3A, but increased tree island flooding is predicted for WCA 3B, northeast Shark River Slough and southern WCA 2A (**Figure 4-9c**). A possible anomaly appears in the MAMFI values for the natural system (**Figure 4-9a**), which shows the expected high scores everywhere except northeast Shark River Slough, where index values are low. This could be an indication of a need to better calibrate the flood index to accommodate deeper regions of the ridge and slough landscape. Alternatively, the low scores could be artifacts of the NSM model topography for northeast Shark River Slough, which has not been adjusted for soil subsidence that is believed to have occurred in this area (Stober et al. 1998).

Drought Index

The spatial distribution of the MAMDI for the natural, current, and restored systems is illustrated in **Figure 4-10**. The natural system receives relatively high scores throughout the ridge and slough landscape (**Figure 4-10a**). In the current system, the index correctly identifies areas of northern WCA 3A, northern LNWR and northeastern WCA 2B that have been subject to significant impacts from drought (**Figure 4-10b**). The restored system shows improvement over the current system; however, relatively low index values are still observed in parts of northern WCA 3A and northern LNWR, and index values in central and southeastern WCA 2A and in eastern WCA 2B are slightly lower than those for the current system (**Figure 4-10c**).

Tree Island Suitability Index

The spatial distribution of the composite TISI for the natural, current, and restored systems is illustrated in **Figure 4-11**. Results for the natural system indicate generally favorable conditions for tree islands throughout the ridge and slough landscape, with the exception of northeast Shark River Slough, again associated with low values for the flood index (**Figure 4-11a**). The index correctly identifies the most heavily impacted areas in WCA 3A in the current system (**Figure 4-11b**). The failure to identify observed impacts to tree islands in WCA 2A is probably a result of the operational assumptions used in modeling the current system. Water levels were simulated using the existing regulation schedule for WCA 2A, which differs from and is more favorable than past operations that resulted in impacts to tree islands in this area (Dineen 1972, 1974). The index values for the restored system suggest that tree island conditions will improve considerably in WCA 3A and Shark River Slough, with slight improvements in northern WCA 2A (**Figure 4-11c**). However, conditions in southern WCA 2A and WCA 3B are predicted to decline slightly in the simulated restored system.

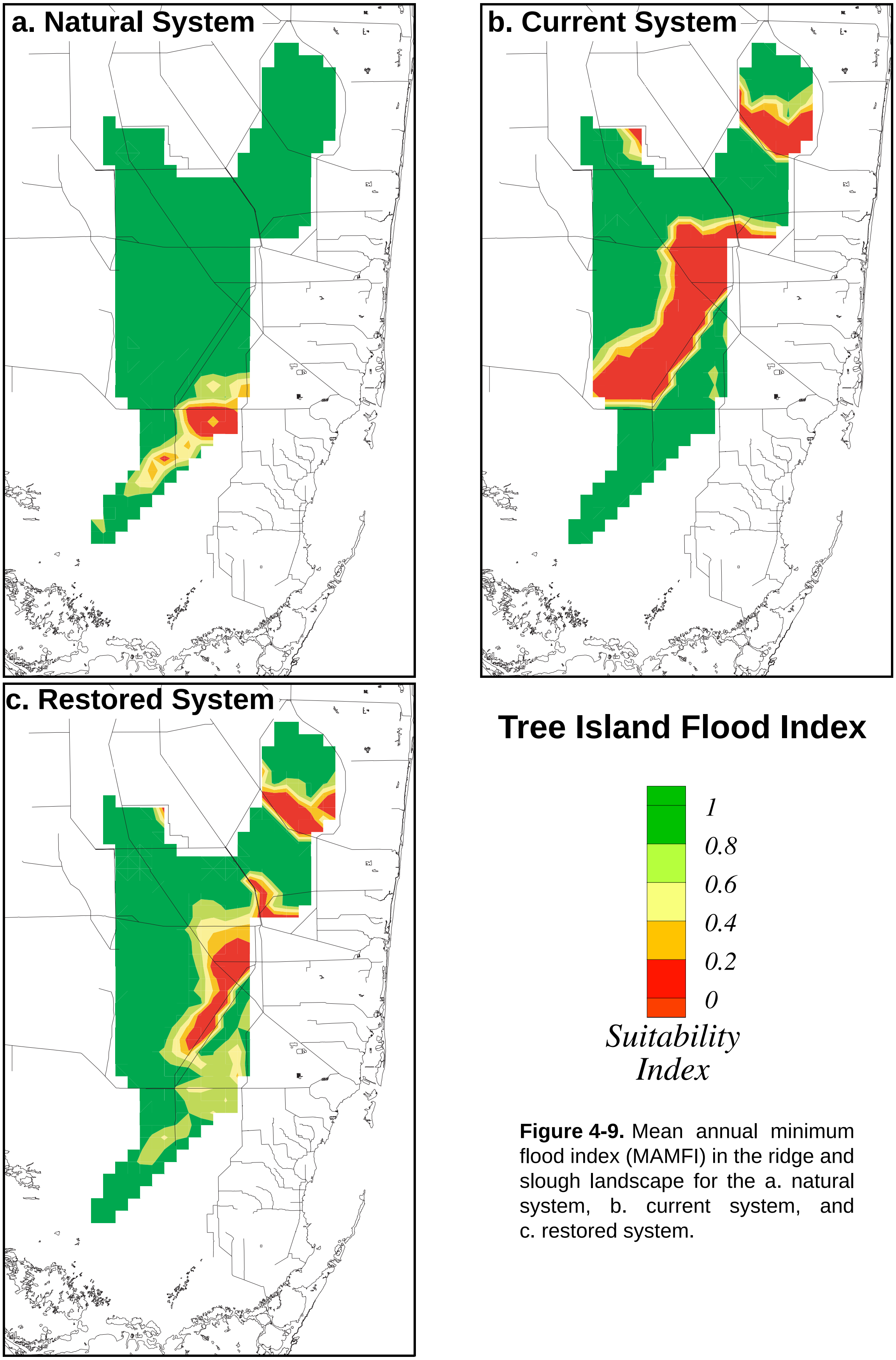


Figure 4-9. Mean annual minimum flood index (MAMFI) in the ridge and slough landscape for the a. natural system, b. current system, and c. restored system.

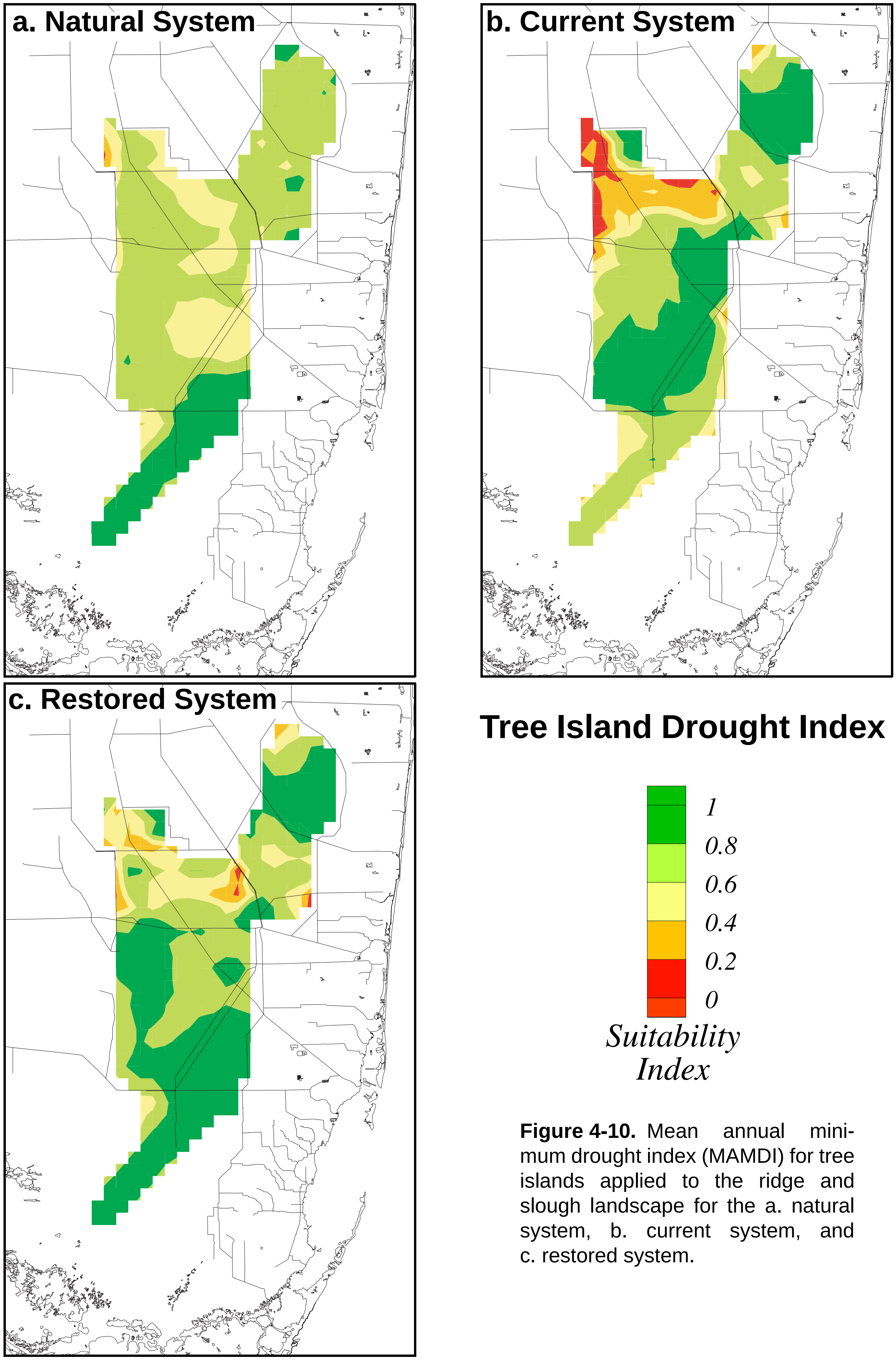
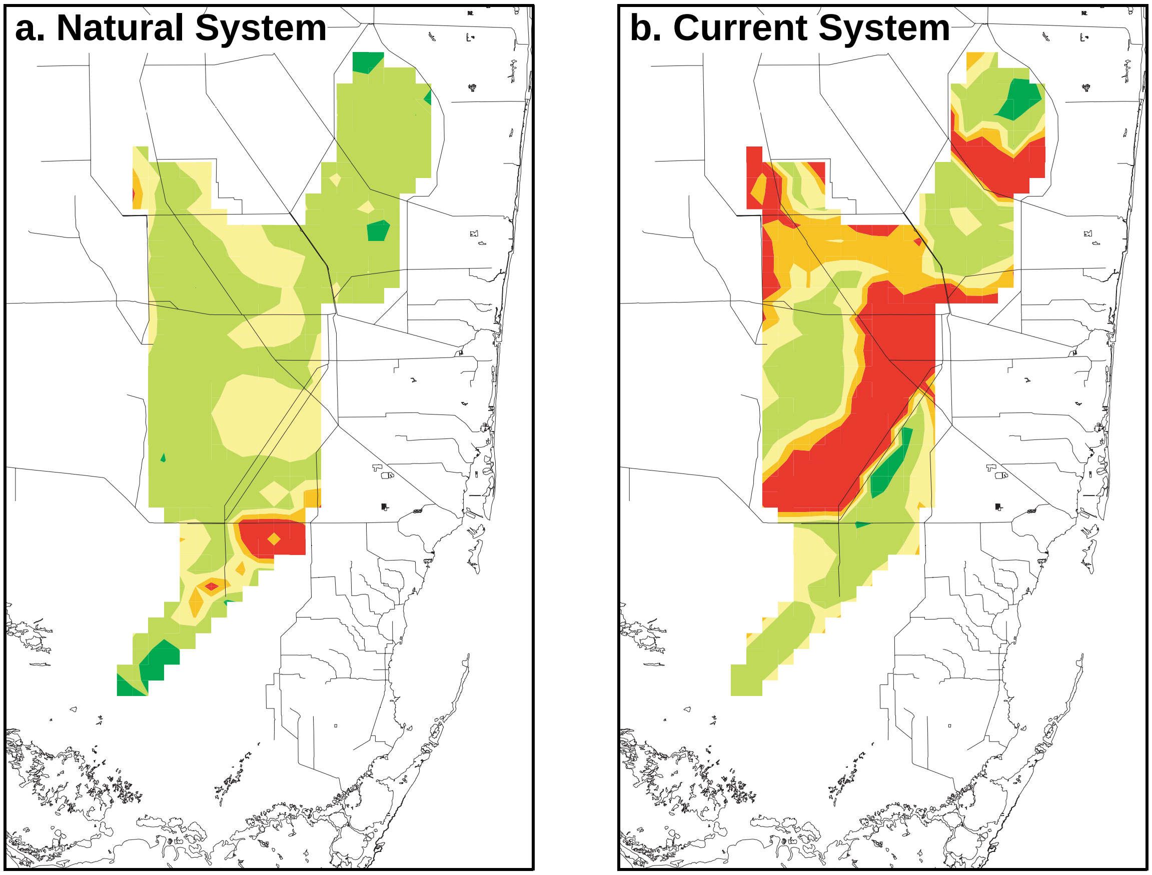
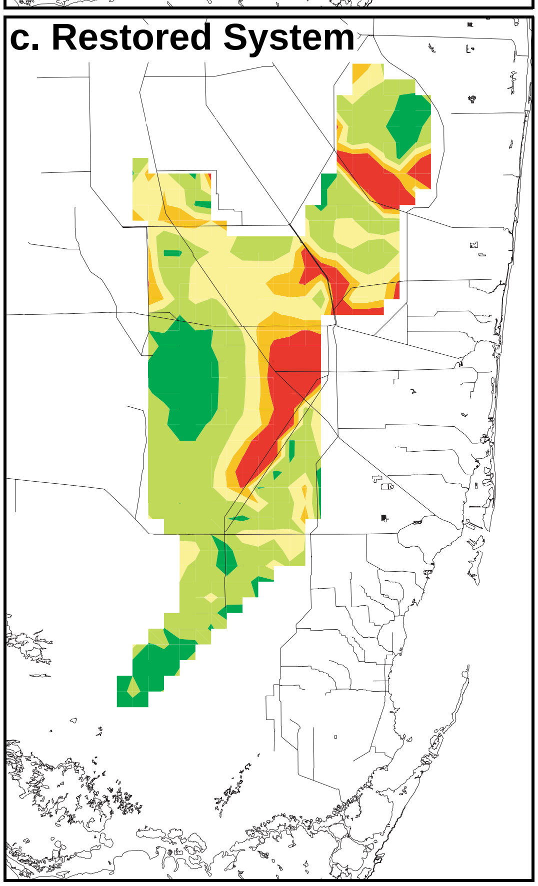


Figure 4-10. Mean annual minimum drought index (MAMDI) for tree islands applied to the ridge and slough landscape for the a. natural system, b. current system, and c. restored system.





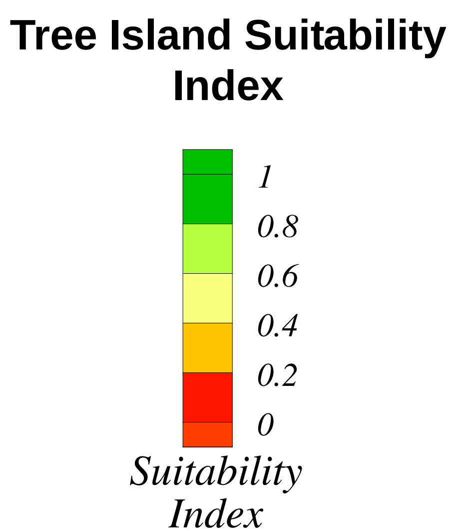


Figure 4-11. Tree island suitability index (TISI) in the ridge and slough landscape for the a. natural system, b. current system, and c. restored system.

Discussion

Figures 4-8 and **4-11** show the spatial distribution of the two indices, SRSI and TISI, across the ridge and slough landscape. For both the current and restored systems, the two indices exhibit similar overall landscape patterns. However, two broad differences are apparent.

First, SRSI exhibits more low (< 0.2) and high (> 0.8) scores (red and green) and fewer intermediate scores than does TISI; it is therefore a more "decisive" index. For the current system, of the 437 model cells representing the ridge and slough landscape, SRSI assigned intermediate (0.0 < SRSI < 1.0) values to 198 cells (45 percent of the area), whereas TISI assigned intermediate values to 399 cells (91 percent of the area). Given this, TISI may be more useful than SRSI in making comparisons among similar model scenarios that have small differences in index scores. However, if index values are uncertain, small differences may be uninformative, and a "blunt" tool such as SRSI may be preferable.

Second, TISI assigns lower scores to areas that have been subject to tree island flooding, and higher scores to areas subject to frequent drought, when compared to SRSI. An explanation for this can be found in the ranges of values of the component indices that contribute to TISI. The flood index MAMFI (**Figure 4-9**) exhibits a larger range of values than does the drought index MAMDI (**Figure 4-10**), having more scores in the "red" zone and fewer intermediate values. Because TISI is based on the product of the annual minima of the two indices, TISI produces lower values in flooded areas than in dry areas. The values of the flood and drought indices are not standardized relative to each other; hence, the difference in their contribution to the final TISI score may not be ecologically meaningful. Using $TISI_{alt}$, the alternative index based on the annual minimum of either MAMFI or MAMDI, does not overcome this inadvertent emphasis on the flood index.

The weighting of the flood and drought scores in SRSI is derived from a multiple regression analysis of species richness on drought and flood measures, and thus these weights employ the statistically observed contribution of the two hydrologic variables as predictors of species richness. This may in principle provide a more ecologically meaningful weighting system. However, it is important to note that the tree island data used to develop SRSI come from an area in which drought impacts have accumulated over a much longer period of time than have impacts from island flooding. Loveless (1959) reported significant fire damage to tree islands in northern WCA 3A by the 1950s. This was well before the impoundment of WCA 3A in the mid-1960s that introduced excess flooding as a significant factor affecting tree islands. It is therefore quite possible that SRSI may implicitly weigh drought impacts disproportionately relative to flood impacts, simply because they have accumulated over a longer period of time. Given these interpretive issues, it can be seen that neither index is expected to correctly predict the *relative* importance of flood versus drought as tree island stressors. Rather, the indices should only be used to make model-to-model comparisons between matched regions of the model domain and should not be used to compare impacts in flooded regions to those in drained ones.

An important issue to be addressed regarding use of the habitat suitability indices is the degree to which the indices can be generalized for application to all parts of the ridge and slough landscape. Both SRSI and TISI were based on data and expertise associated with particular subregions. SRSI was derived using data from tree islands in WCA 3A (Heisler et al. 2002); TISI was based on field data and landscape modeling in WCA 2A (Wu et al. 1996, 1997) and WCA 3A (Wu et al. 2002). Whether or not they are broadly applicable across the entire ridge and slough landscape remains to be assessed.

Drought impacts to tree islands are mediated by common causal mechanisms of microbial oxidation and fire; thus, one would expect that an index suitable for one region of the peat-forming Everglades should apply to all such regions. It is possible, however, that if regions differ in soil thickness, the drought index may provide scores that are not comparable between regions by assigning similar values to areas that differ in vulnerability to fire. This reinforces the need to avoid cross-region comparisons.

Flooding effects are less likely than are drought effects to share common evaluation criteria across the ridge and slough landscape. Generalization of the flood index across regions requires a consideration of regional variation in tree island height and composition. For example, LNWR is a unique area having numerous and distinctive “pop-up” tree islands, which may respond differently to high water conditions than the large fixed tree islands in WCA 3 and Shark River Slough. Likewise, Shark River Slough is a region where historic depths probably exceeded those in the ridge and slough landscape to the north. In a restored ecosystem, similar tree island vegetation communities in Shark River Slough might occur at higher relative elevations than they would on islands in the water conservation areas.

Given our limited present knowledge of tree island elevations and the nature of flooding effects, SRSI may be more safely generalized to areas outside of WCA 2 and WCA 3 than TISI. SRSI is based on two variables, frequencies of depths above 2.0 feet and below -1.0 foot, that can serve broadly as indicators of extreme depth conditions so long as they are scaled appropriately for each region. Because SRSI uses the local natural system (NSM) hydrology to define its target, scaling to different NSM hydropatterns is built directly into the index. In contrast, TISI employs absolute benchmarks for acceptable depths and durations of high and low water. Thus, TISI is more likely to require calibration in order to be applied in different regions. A drawback to the use of SRSI, is that it assumes that the NSM provides an accurate representation of historical hydropatterns as well as a good approximation of the depth conditions that would support tree islands in the current, modified Everglades landscape. The utility of SRSI is thus tied to the validity of NSM hydrology as a restoration target. Given these caveats, the use of SRSI to evaluate tree island impacts in LNWR and Shark River Slough may be reasonable.

Application of either TISI or SRSI in the remnant sawgrass plains of northeastern WCA 3A and the Holey Land Wildlife Management Area is not warranted, owing to the absence of tree islands in these areas. However, the use of the drought index MAMDI seems both appropriate and valuable in these regions, owing to their histories of overdrainage and peat fire. The Rotenberger Wildlife Management Area contains tree islands that have lost elevation owing to past wildfires. In this area (and possibly others yet to be identified), the use of natural system hydrology to define appropriate high water values may be inappropriate, and SRSI may not be applicable without modification of its "target" value.

In summary, SRSI is probably more likely to be broadly applicable across the ridge and slough landscape, because it is unambiguously tied to empirical data, is simpler in structure, and is scaled to match spatial variation in hydropatterns estimated by NSM. TISI shows promise as a method for providing a representation of stress and recovery of islands as a function of hydrologic change over time. At present, application of TISI may best be restricted to WCA 2A and WCA 3A, pending additional cross-validation and calibration. Overall, the most robust evaluations may be achieved by applying both indices simultaneously. This approach would enable planners to explicitly consider the strengths and limitations of both indices, and to use differences between index results to identify areas where the response of tree islands to proposed hydrologic change is least certain.

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